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Data Article

Mechanical testing data from neutron irradiations of PM-HIP and conventionally manufactured nuclear structural alloys

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ABSTRACT

This article presents the comprehensive mechanical testing data archive from a neutron irradiation campaign of nuclear structural alloys fabricated by powder metallurgy with hot isostatic pressing (PM-HIP). The irradiation campaign was designed to facilitate a direct comparison of PM-HIP to conventional casting or forging. Five common nuclear structural alloys were included in the campaign: 316L stainless steel, SA508 pressure vessel steel, Grade 91 ferritic steel, and Ni-base alloys 625 and 690. Irradiations were carried out in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL) to target doses of 1 and 3 displacements per atom (dpa) at target temperatures of 300 and 400 °C. This article contains the data collected from post-irradiation uniaxial tensile tests following ASTM E8 specifications, fractography of these tensile bars, and nanoindentation. By making this systematic and valuable neutron irradiated mechanical behavior dataset openly available to the nuclear materials research community, researchers may now use this data to populate material performance databases, validate material

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performance and hardening models, design follow-on experiments, and enable future nuclear code-qualification of PM-HIP techniques.

Specifications Table

Subject	Material Characterization
Specific subject area	Neutron irradiation effects on the mechanical behavior of nuclear reactor structural alloys, including steels and Ni-base alloys.
Type of data	Table – Data tables are provided from uniaxial tensile testing and nanoindentation testing Image – Images are provided from nanoindentation testing and fracture surface characterization (after uniaxial tensile testing)
How the data were acquired	Three primary sets of data were collected: (1) uniaxial tensile testing of round tensile bars, (2) fracture surface imaging of broken tensile specimens, and (3) nanoindentation on 3 mm disc specimens. Uniaxial tensile data was collected using a 13M Instron load frame located inside the hot cells at the Hot Fuel Examination Facility (HFEF) at Idaho National Laboratory (INL). Testing was conducted in accordance with ASTM standard E8 for threaded grip specimens. Tensile testing was conducted at ambient temperature in an argon environment. Strain rate was 8.78×10^{-3} s^{-1}, which corresponds to a crosshead speed of 0.279 mm/min. After 10% strain, the strain rate was increased to 0.0315 s^{-1} (crosshead speed 1.0 mm/min) until failure. Following tensile testing, selected fracture surfaces of interest were sectioned from the broken tensile specimens so that the fracture surface could be accommodated within a scanning electron microscope (SEM) for fractography. Fractography was conducted using a Lyra3 Tescan SEM, also at HFEF at INL. Nanoindentation was conducted on disc specimens (3 mm diameter, ~250 µm thickness) after surfaces were prepared by jet electropolishing in a 90% methanol + 10% perchloric acid solution at -20 °C. A Berkovich indenter tip was used in continuous stiffness mode. For the SA508 specimens, nanoindentation was conducted in load-controlled mode to a maximum load of 8000 µN with a loading time of 5 s, holding time of 5 s, and unloading time of 5 s. For all other alloys, nanoindentation was conducted in depth-controlled mode to a maximum depth of 3500 nm at a strain rate of 0.2 s^{-1}. Indents were generally made in 6 × 5 indent arrays. All nanoindentation was conducted using a Hysitron TI-950 TriboIndenter operating in ambient temperature and atmosphere. Note that alloy composition was measured using inductively coupled plasma atomic emission spectroscopy (ICP-AES).
Data format	Raw – All data is provided in raw form
Description of data collection	Uniaxial tensile data was conducted at ambient temperature in an argon environment within a hot cell. The applied strain rate was 8.78×10^{-3} s^{-1} until 10% strain was achieved, after which the strain rate was increased to 0.0315 s^{-1} until failure. Fractography of selected fracture surfaces was conducted at ambient temperature in a high vacuum environment within a SEM. Nanoindentation was conducted at ambient temperature in an atmospheric air environment. Berkovich nanoindentation was conducted at a strain rate of 0.2 s^{-1} using a loading time of 5 s, holding time of 5 s, and unloading time of 5 s.
Data source location	Uniaxial tensile data and fracture surface images: Idaho National Laboratory Idaho Falls, ID USA Nanoindentation data: Center for Advanced Energy Studies Idaho Falls, ID USA

(continued on next page)

Data accessibility	Repository name: Mendeley Data Data identification number: 10.17632/9z98kdkpyz.1 Direct URL to data: 10.17632/9z98kdkpyz.1
Related research article	C. Clement, S. Panuganti, P.H. Warren, Y. Zhao, Y. Lu, K. Wheeler, D. Frazer, D.P. Guillen, D.W. Gandy, J.P. Wharry, Comparing structure-property evolution for PM-HIP and forged alloy 625 irradiated with neutrons to 1 dpa, Mater. Sci. & Engr. A 857 (2022) 144058. 10.1016/j.msea.2022.144058

Value of the Data

- Data represent a comprehensive mechanical characterization of unique neutron irradiated powder metallurgy - hot isostatically pressed (PM-HIP) structural alloys, with a direct comparison to the cast or forged counterpart alloy. Direct comparisons of advanced manufactured materials to their conventionally manufactured counterparts – particularly under neutron irradiation – are rare.
- Neutron irradiation experiments are costly, time-consuming, and challenging, so the resultant data can offer considerable value to the nuclear materials and irradiation effects research communities.
- Historical data from neutron irradiated materials (especially legacy power plant materials) have been poorly archived in the open, accessible literature. By making the data herein open and permanently accessible, we aim to contribute to growing this critical database.
- Researchers working in irradiation effects and nuclear reactor materials may be able to use these data to enhance our overall understanding of mechanical behavior of structural alloys under neutron irradiation, and guide future mechanistic experiments.
- Data can support future nuclear code qualification efforts for PM-HIP alloys.
- Data can be used for verification and validation of predictive mechanics models for nuclear structural material lifetimes and performance, including use as training data for machine learning models.

1. Objective

The objective is to publish the mechanical behavior data from neutron irradiated structural alloys fabricated by both powder metallurgy with hot isostatic pressing (PM-HIP) and conventional casting or forging. Neutron irradiations with post-irradiation examination (PIE) are required to qualify advanced materials for nuclear reactor service. But these neutron irradiation and PIE campaigns are time-consuming, often spanning 7 or more years, and can cost multiple millions of dollars partially because of the precautions necessary for characterizing radioactive specimens. Hence, data generated from these campaigns is of tremendous value to the nuclear materials and irradiation effects research communities. Here, we publish a comprehensive neutron irradiated mechanical testing dataset that enables direct comparisons of PM-HIP alloys to their cast/forged counterparts. Alloys studied are 316L stainless steel, SA508 pressure vessel steel, Grade 91 ferritic steel, and Ni-base alloys 625 and 690. Irradiations were carried out in the Advanced Test Reactor (ATR) to target doses of 1 and 3 displacements per atom (dpa) at target temperatures of 300 and 400 °C. Mechanical data included are ASTM E8 uniaxial tensile tests, fractography, and nanoindentation. This data can be used to populate material performance databases, validate models, design follow-on experiments, and enable future code-qualification of PM-HIP manufacturing.

2. Data Description

Nanoindentation, uniaxial tensile testing, and fractography are conducted on five nuclear structural alloys fabricated by PM-HIP and a conventional method (specifically, casting or forging), then irradiated to a range of doses and temperatures. The specific forms of data are:

Tensile Data – Raw data are provided in .csv format. Each data file corresponds to a single tensile specimen. Files contain a header with metadata including the specimen name, testing conditions, and experiment date and operator. The remainder of each file contains the tabulated measured stress-strain curve.

Fractography Data – Files are organized into folders by specimen (i.e., broken tensile bar). Multiple image files are collected from each specimen. Typically, an "overview" image is provided, with numerous additional higher-magnification images of representative areas on the fracture surface. All fractographs are provided in software-agnostic .jpg, .bmp, or .tiff format.

Nanoindentation Data – Files are organized into folders by specimen. Each folder contains three file types:

(1) One "Read Me" .txt file: The first line of these files lists the total number of indents, N, made on the given specimen (typically $N = 20–30$ indents per specimen). The remainder of this file lists the file names corresponding to each of these N indents and tabulates key indentation results and parameters, specifically: maximum indent depth h_{max} (nm), characteristic depth h_c (nm), maximum load P_{max} (μN), stiffness S (μN/nm), indent area A (nm^2), effective depth h_{eff} (nm), reduced modulus E_r (GPa), and hardness H (GPa). These values can be used with the corresponding raw data files (see #2 below) to calculate H versus depth and E versus depth curves, per the Oliver-Pharr method.
(2) A total of N raw data .txt files, each corresponding to one of the indents made on the given specimen. Indent depth (nm), load (μN), and time (s) are tabulated throughout the duration of each indent, from initial to deepest indent depths. Load-displacement curves can be generated from these raw data.
(3) Some specimen ID numbers will have an associated .jpg image that displays the array of indents made on the specimen. Images were not collected for all specimens, so are not available for all specimens (i.e., in all folders).

3. Experimental Design, Materials and Methods

This article presents a complete dataset from the mechanical testing conducted as part of a neutron irradiation campaign [1–3] aiming to directly compare the irradiation behavior of five PM-HIP [4–6] nuclear structural alloys to their conventional cast or forged counterparts. The intention of this article is to make this high-value, systematic neutron irradiated mechanical behavior dataset openly and permanently available to the nuclear materials community for research and practical purposes such as populating material performance databases, validating hardening models, designing follow-on experiments, and providing materials qualification data.

3.1. Materials and Irradiations

Five common nuclear structural alloys were studied, specifically 316L stainless steel, SA508 Grade 3 Class 1 pressure vessel steel, Grade 91 ferritic steel, and two Ni-based alloys 625 and 690. All five alloys had a PM-HIP version and a conventionally manufactured (cast or forged) version. Alloy compositions measured by ICP-AES and processing parameters are provided in Tables 1 and 2, respectively. The unirradiated thermal and mechanical behaviors of Alloys 625, 690, and 316L have been documented in Refs. [7–9] and the ion irradiation response of Alloy 625 in Ref. [10]. From each alloy, specimens were machined into either transmission electron microscopy (TEM) discs or round tensile bars, Fig. 1. The TEM discs were cut by wire electrical

Table 1
Alloy compositions in wt%, measured by ICP-AES.

Alloy	Fabrication	C	Si	Mn	P	S	Cr	Ni	Mo	Ti	Cu	Al	Co	Pb	Fe	V	Nb	N
625	PM-HIP	0.01	0.45	0.41	0.003	0.003	21.9	Bal	8.2	0.006	<0.1	<0.05	<0.1	<0.010	3.6	–	–	–
625	Forged	0.01	0.20	0.42	0.006	0.004	23.7	Bal	7.6	0.31	–	0.02	–	–	3.5	–	3.6	–
690	PM-HIP	0.019	0.45	0.37	–	0.003	30.9	Bal	–	–	0.01	<0.02	–	–	9.6	–	–	–
690	Forged	–	0.12	0.59	–	0.003	31.3	Bal	–	0.31	–	0.26	–	–	10.3	–	–	–
Grade 91	PM-HIP	0.12	0.47	0.62	0.004	0.003	8.78	0.08	0.92	–	–	0.12	–	–	Bal	0.27	–	–
Grade 91	Cast	0.10	0.24	0.48	0.004	0.008	8.40	0.09	0.86	–	–	0.05	–	–	Bal	0.20	–	–
SA 508	PM-HIP	0.01	0.21	1.39	0.002	0.005	0.18	0.79	0.37	–	–	–	–	–	Bal	–	–	–
SA 508	Forged	0.02	0.31	0.46	0.003	0.007	0.21	0.50	0.26	–	–	–	–	–	Bal	0.01	–	–
316L	PM-HIP	0.004	0.88	1.41	0.005	0.005	17.6	12.5	2.10	–	–	–	–	–	Bal	–	–	<0.1
316L	Forged	0.03	0.52	1.52	0.045	<0.03	16.3	10.7	1.86	–	0.35	–	–	–	Bal	–	–	<0.1

Table 2
Alloy processing parameters [18].

Alloy	HIP Parameters (Pressure, Temperature, Time)	Heat Treatment
625	15 ksi, 1149 °C, 4 h	Solution cycle 1171 ± 14 °C, 2 h; water quench
690	15 ksi, 1149 °C, 4 h	Solution cycle 1177 ± 14 °C, 2 h; water quench
Grade 91	15 ksi, 1121 °C, 4 h	Normalize 1060 ± 14 °C, 2.5 h; forced air fan cooling; temper 777 ± 14°C, 4.5 h; air cooling
SA 508	15 ksi, 1121 °C, 4 h	Solution cycle 1121 °C, 2 h; water quench; normalize 899 °C, 10 h; water quench; temper 649 °C, 10 h; air cooling
316L	15 ksi, 1121 °C, 4 h	Solution cycle 1066 ± 14 °C, 1 h; water quench

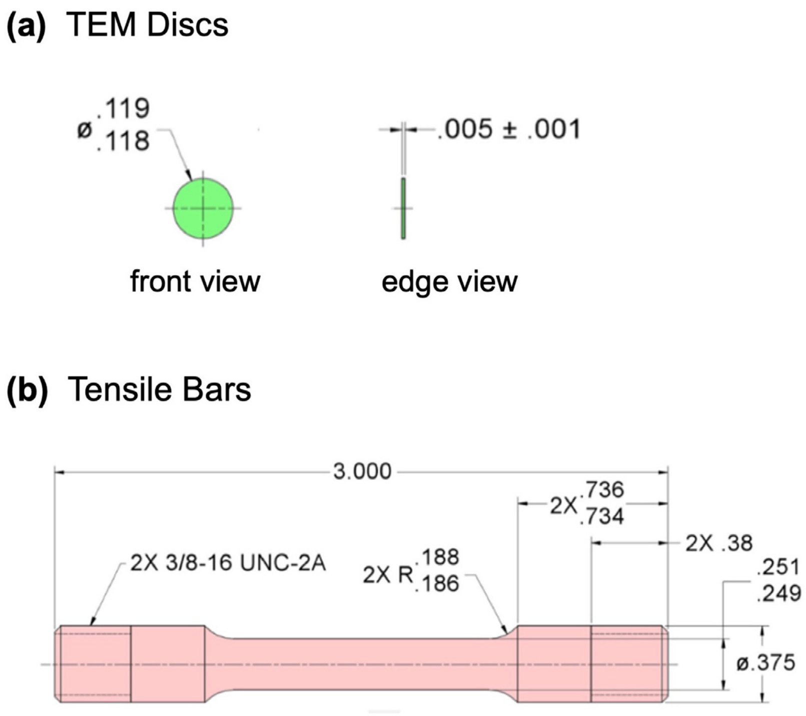

Fig. 1. Specimen geometries of (a) TEM discs and (b) tensile bars (all dimensions in inches).

Table 3
List of files for 304L stainless steel specimens.

Fabrication	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoindent	Tensile	Fractography
Cast	701	Tensile	3	400	2.98	388	–	Yes	–
	702	Tensile	3	400	3.36	398	–	Yes	–
	722	Tensile	3	400	3.15	379	–	Yes	–
	723	Tensile	3	400	2.70	385	–	Yes	–

Table 4
List of files for 316L stainless steel specimens.

Fabrication	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoindent	Tensile	Fractography
Cast	643	TEM Disc	3	400	3.83	396	Yes	–	–
	704	Tensile	3	400	3.84	379	–	Yes	–
	705	Tensile	3	400	3.94	382	–	Yes	–
PM-HIP	646	TEM Disc	3	400	4.00	397	Yes	–	–
	719	Tensile	3	400	3.91	380	–	Yes	–
	720	Tensile	3	400	3.77	373	–	Yes	Yes

discharge machining (EDM) to 3 mm in diameter and ~250 µm thick. They were subsequently hand polished using successively finer diamond suspensions (to the finest suspension of 1 µm diamond) to achieve a mirror finish and a final disc thickness of 150 µm for compliance with dimensions shown in Fig. 1. The tensile specimen geometries were guided by ASTM standard E8, having a total length of 76.2 mm (3 in) and gauge diameter of 6.35 mm (0.25 in). The tensile specimens were cut by computer numerical control (CNC) machining to a surface roughness of 3.2 µm. Each specimen was engraved with a unique identification (ID) number.

Following machining and dimensional inspections, specimens were loaded for irradiation experiments into non-instrumented stainless steel capsules, which acted as sealed pressure boundaries between the specimens and the reactor coolant. Capsules were pressurized with He or Ar gas to control temperature; quartz-encapsulated melt wires in capsules were used to estimate in-pile temperature history. Capsules were then assembled into test trains for reactor insertion. Additionally, the irradiation experiment design process included structural, thermal, and neutronic analyses as described in Refs. [11,12]. A comprehensive description of the capsule design, assembly, and irradiation experiment design is provided in Ref. [1].

The test trains were loaded into Advanced Test Reactor (ATR) inboard positions A-6, A-7, and A-8. The irradiation occurred during ATR cycles 164A, 164 B, 166A and 166B, between May 9, 2018, and January 10, 2020. The estimated total irradiation dose was calculated using MCNP5 release 1.60 [13,14] using microscopic cross-section data generated by NJOY [15]. Specimen maximum and average temperatures during irradiation were estimated by finite-element analysis in ABAQUS, together with the melt wire analysis, as described in refs. [16,17]. As-run thermal and dose analysis is comprehensively described in Ref. [1].

The actual neutron irradiation doses ranged ~0.5–4.5 displacements per atom (dpa) and actual specimen average temperatures ranged ~260–400 °C. The specific dose and temperature history of each specimen is listed in Tables 3–8, which are organized by alloy. The type of mechanical testing data obtained from each specimen – i.e., nanoindentation, uniaxial tensile testing, and/or fractography – is also specified in Tables 3–8.

3.2. Mechanical Testing of Irradiated Specimens

After neutron irradiation, all specimens are unloaded from their capsules, decontaminated, and sorted within the radioactive material handling host cells at the Hot Fuel Examination Facility (HFEF) at Idaho National Laboratory (INL). From there, tensile specimens were moved within

Table 5
List of files for Alloy 625 specimens.

Fabrication	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoindent	Tensile	Fractography
Forged	Unirrad	TEM Disc	0	0	0	0	Yes	–	–
	Unirrad	Tensile	0	0	0	0	–	Yes	–
	448	TEM Disc	1	400	1.06	385	Yes	–	–
	520	Tensile	1	400	0.71	355	–	Yes	–
	521	Tensile	1	400	0.52	338	–	Yes	Yes
	303	Tensile	3	300	4.32	269	–	–	–
	304	Tensile	3	300	4.43	270	–	Yes	–
	615	TEM Disc	3	400	4.20	398	Yes	–	–
	603	Tensile	3	400	3.84	380	–	Yes	Yes
	604	Tensile	3	400	4.01	392	–	–	–
PM-HIP	Unirrad	TEM Disc	0	0	0	0	Yes	–	–
	Unirrad	Tensile	0	0	0	0	–	Yes	–
	452	TEM Disc	1	400	1.05	385	Yes	–	–
	459	Tensile	1	400	0.73	339	–	Yes	–
	460	Tensile	1	400	0.53	321	–	Yes	Yes
	342	Tensile	3	300	4.40	264	–	Yes	–
	343	Tensile	3	300	4.23	257	–	Yes	–
	609	TEM Disc	3	400	4.27	398	Yes	–	–
	671	Tensile	3	400	3.93	384	–	Yes	–
	672	Tensile	3	400	3.69	367	–	Yes	Yes

Table 6
List of files for Alloy 690 specimens.

Fabrication	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoindent	Tensile	Fractography
Forged	Unirrad	Tensile	0	0	0	0	–	Yes	–
	415	TEM Disc	1	400	1.09	389	Yes	–	–
	518	Tensile	1	400	0.99	358	–	Yes	–
	519	Tensile	1	400	0.86	335	–	Yes	–
	301	Tensile	3	300	3.79	284	–	Yes	–
	302	Tensile	3	300	4.13	306	–	Yes	–
	627	TEM Disc	3	400	4.11	398	Yes	–	–
	601	Tensile	3	400	3.12	373	–	Yes	–
	602	Tensile	3	400	3.52	385	–	Yes	–
PM-HIP	Unirrad	Tensile	0	0	0	0	–	Yes	–
	408	TEM Disc	1	400	1.09	388	Yes	–	–
	457	Tensile	1	400	0.99	342	–	Yes	–
	458	Tensile	1	400	0.86	368	–	Yes	–
	344	Tensile	3	300	3.96	288	–	Yes	–
	345	Tensile	3	300	3.53	266	–	Yes	–
	621	TEM Disc	3	400	4.14	398	Yes	–	–
	673	Tensile	3	400	3.29	378	–	Yes	–
	674	Tensile	3	400	2.82	378	–	Yes	–

the HFEF hot cells for uniaxial tensile testing, while the TEM disc specimens were packaged for shipping to the Center for Advanced Energy Studies (CAES) for nanoindentation testing.

Uniaxial tensile data was collected using a 13M Instron load frame located inside the INL HFEF hot cells. Although this load frame is dedicated for radioactive materials, the unirradiated tensile bars were also tested on this same load frame for consistency and to eliminate effects of instrument variability. Testing was conducted in accordance with ASTM standard E8 for threaded grip specimens. All tensile testing was conducted at ambient temperature in an Ar environment. Strain rate was 8.78×10^{-3} s^{-1}, which corresponds to a crosshead speed of 0.279 mm/min. After 10% strain, the strain rate was increased to 0.0315 s^{-1} (crosshead speed 1.0 mm/min) until failure.

Following tensile testing, some specimens of interest were selected for fractography. To prepare specimens for fractography, ~1-2 mm (including the fracture surface) was cut off the end

Table 7
List of files for Grade 91 steel specimens.

Fabri cation	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoi ndent	Tensile	Fracto-graphy
Cast	Unirrad	Tensile	0	0	0	0	–	Yes	–
	425	TEM Disc	1	400	0.99	389	Yes	–	–
	503	Tensile	1	400	1.00	386	–	Yes	Yes
	504	Tensile	1	400	0.99	376	–	Yes	–
	666	TEM Disc	3	400	3.97	397	Yes	–	–
	605	Tensile	3	400	3.71	363	–	Yes	–
	703	Tensile	3	400	3.54	362	–	Yes	Yes
PM-HIP	Unirrad	Tensile	0	0	0	0	–	Yes	–
	424	TEM Disc	1	400	0.99	389	Yes	–	–
	403	Tensile	1	400	1.02	367	–	Yes	Yes
	404	Tensile	1	400	1.01	358	–	Yes	–
	636	TEM Disc	3	400	3.74	397	Yes	–	–
	605	Tensile	3	400	3.71	363	–	Yes	–
	670	Tensile	3	400	3.68	362	–	Yes	Yes
	721	Tensile	3	400	3.40	351	–	Yes	–

Table 8
List of files for SA508 steel specimens.

Fabri cation	Specimen ID	Specimen Type	Target Dose [dpa]	Target Temp [°C]	Actual Dose [dpa]	Actual Avg Temp [°C]	Nanoi ndent	Tensile	Fracto-graphy
Forged	Unirrad	TEM Disc	0	0	0	0	Yes	–	–
	Unirrad	Tensile	0	0	0	0	–	Yes	–
	110	TEM Disc	1	300	0.69	286	Yes	–	–
	114	TEM Disc	1	300	0.69	286	Yes	–	–
	201	Tensile	1	300	0.53	265	–	Yes	–
	206	Tensile	1	300	0.83	270	–	Yes	–
	437	TEM Disc	1	400	0.95	384	Yes	–	–
	501	Tensile	1	400	0.96	362	–	Yes	–
	502	Tensile	1	400	0.98	385	–	Yes	Yes
PM-HIP	Unirrad	TEM Disc	0	0	0	0	Yes	–	–
	Unirrad	Tensile	0	0	0	0	–	Yes	–
	104	TEM Disc	1	300	0.70	286	Yes	–	–
	101	Tensile	1	300	0.54	266	–	Yes	–
	127	Tensile	1	300	0.84	273	–	Yes	–
	434	TEM Disc	1	400	0.98	388	Yes	–	–
	401	Tensile	1	400	0.97	343	–	Yes	Yes
	402	Tensile	1	400	1.00	365	–	Yes	–

of one of the broken “halves” of the tensile bar. Cutting was done with a low-speed saw, and the cut was made normal to the tensile axis. This allowed for the fracture surface to be accommodated face-up within a scanning electron microscope (SEM) for fractography, and also minimized the radioactive material volume within the SEM. The cutting was done in the hot cells in HFEF, then specimens were subsequently moved into the Lyra3 Tescan SEM, also at HFEF at INL. SEM images were collected in secondary electron (SE) mode. An overview image of the entire fracture surface was taken for each specimen of interest. Additional images were taken to show representative features of the fracture surface in higher magnification and detail.

Nanoindentation was conducted on the TEM disc specimens shipped to CAES. Their surfaces were first prepared by jet electropolishing in a 90% methanol + 10% perchloric acid solution maintained at -20 °C. A Berkovich indenter tip was used in continuous stiffness mode. For the SA508 specimens, nanoindentation was conducted in load-controlled mode to a maximum load of 8000 µN with a loading time of 5 s, holding time of 5 s, and unloading time of 5 s. For all other alloys, nanoindentation was conducted in depth-controlled mode to a maximum depth of 3500 nm at a strain rate of 0.2 s^{-1}. Indents were generally made in 6 × 5 indent arrays. All nanoindentation was conducted using a Hysitron TI-950 TriboIndenter at CAES operating in ambient temperature and atmosphere.

Ethics Statements

This work did not involve human subjects, animal experiments, or data collected from social media platforms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

PM-HIP Mechanical Data Archive (Original data) (Mendeley Data).

CRediT Author Statement

Janelle P. Wharry: Conceptualization, Project administration, Supervision, Funding acquisition, Writing – original draft; **Caleb D. Clement:** Investigation, Data curation, Writing – review & editing; **Yangyang Zhao:** Investigation, Data curation, Writing – review & editing; **Katelyn Baird:** Investigation, Writing – review & editing; **David Frazer:** Investigation, Writing – review & editing; **Jatuporn Burns:** Investigation, Writing – review & editing; **Yu Lu:** Investigation, Writing – review & editing; **Yaqiao Wu:** Investigation, Writing – review & editing; **Collin Knight:** Project administration, Supervision, Writing – review & editing; **Donna P. Guillen:** Project administration, Supervision, Funding acquisition, Writing – review & editing; **David W. Gandy:** Conceptualization, Project administration, Funding acquisition, Writing – review & editing.

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